

Valley Agricultural Systems in Prehistoric Hawaii: An Archaeological Consideration

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INTRODUCTION

INDIGENOUS Oceanic agricultural systems have concerned anthropologists for decades, an extension of an older botanical concern with Malayo-Oceanic flora, including cultigens. Only in the past few years, however, have hypotheses concerning the development of agriculture in Oceania moved beyond ethnobotanical speculation to attempts at direct archaeological testing. The earlier botanical and anthropological studies provided the basic characterization of Oceanic agriculture as based on an adventive crop plant inventory of indigenous Asiatic species (with the exception of certain New Guinea or Melanesian domesticates, and of the sweet potato), with successive reduction in total numbers of cultivable species from west to east. Barrau (1958, 1961, 1965) especially has drawn attention to the range of agronomic modifications of edaphic and hydrologic conditions by which cropping of otherwise unfavorable environments has been realized. The particular processes of transfer of both crop plant inventories and agricultural techniques (i.e., agricultural systems; cf. Conklin 1954, 1957; Brookfield 1968: 414-415; Harris 1969), and the segregative effects of island environments, are matters of increasing concern to the Oceanic prehistorian (Yen 1973). This paper is an attempt at synthesis of recent archaeological investigation of indigenous Hawaiian agriculture, one of several East Polynesian endpoints in the sequence of transfer of Pacific agricultural systems. This study encompasses only *valley* systems, i.e., systems in areas where the natural landscape has been significantly modified or dissected by drainage; thus, we are eliminating from consideration both relatively undissected flow slopes and saddle or plateau regions (Rosendahl 1972; Soehren and Newman 1968). It is hoped

that this archaeological perspective will not only define the nature of indigenous systems in this archipelago but also suggest certain methodological approaches which may be of value in further palaeoethnobotanic investigations in Malayo-Oceania.

Ethnohistoric consideration of the European contact-period endpoint of Hawaiian agriculture (Handy and Handy 1972) provides a baseline for prehistoric reconstruction. Such data clearly suggest that Hawaiian cultivation systems included both intensive and extensive aspects, and were based on the farinaceous root-crop dominants of taro (*Colocasia esculenta* [L.] Schott), sweet potato (*Ipomoea batatas* [L.] Lam.), and the greater yam (*Dioscorea alata* L.). Other herbaceous and arborescent species provided a secondary element, including coconut (*Cocos nucifera* L.), breadfruit (*Artocarpus altilis* [Parkinson ex Z] Fosberg), banana (*Musa* hybrids), sugarcane (*Saccharum officinarum* L.), the bitter yam (*D. bulbifera* L.), and *D. pentaphylla* L. cvr. PIIA St. John, the elephant ear (*Alocasia macrorrhiza* [L.] Schott), the *ti* plant (*Cordyline fruticosa* [L.] A. Chevalier), and the Polynesian arrowroot (*Tacca leontopetaloides* [L.] Kuntze). A certain component of the cultigens was grown rather for material uses than for subsistence, such as paper mulberry (*Broussonetia papyfera* [L.] Vent.), the bottle gourd (*Lagenaria siceraria* [Molina] Stand.), the screwpine (*Pandanus odoratissimus* L. f. *sens. lat.*), hibiscus (*Hibiscus tiliaceus* L.), turmeric (*Curcuma longa* L.), the *noni* (*Morinda citrifolia* L.), and *olona* (*Touchardia latifolia* Gaudichaud). A narcotic element was represented by kava (*Piper methysticum* Forst.). An additional economic subsystem, animal husbandry (dogs, pigs, fowl), was also integrated into the agricultural subsistence base (Handy and Handy 1972: 242–252). The absence of certain common Polynesian species, such as *Inocarpus fagiferus* (Parkinson ex Z) Fosberg or *Spondias dulcis* Forster, can be attributed to the segregative effects of island transfer of agricultural systems referred to previously.

Intensiveness of indigenous adaptation to the environmental range provided by the Hawaiian archipelago, in terms of both crop scheduling and structural modifications of edaphic media, is also amply indicated in the ethnohistoric literature (Arago 1823: 120; Cook 1784: 204, *passim*; Kotzebue 1821: 340–341; Macrae 1922: 9; Mathison 1825: 379; Stewart 1830: 143; Vancouver 1801: 375). Early accounts stress, for example, irrigated aspects of the indigenous valley system at Waimea, Kauai Island (Cook 1784: 225, 244; Portlock 1789: 191–192; Menzies 1920: 28–29):

. . . these plantations were divided by deep and regular ditches; the fences were made with a neatness approaching elegance, and the roads through them . . . would have done credit to any European engineer. . . (King 1784: vol. 3, 116)

HAWAIIAN VALLEY ENVIRONMENT

The general characteristics of island ecosystems, such as small size and resource limitation, in contrast to larger land masses, are discussed by Fosberg (1965). Geologically, each of the islands is composed of one or more volcanic domes, ranging in height (above sea level) from about 600 to 4000 m, and comprising primarily basaltic or andesitic flow slopes, with the older islands (e.g., Kauai) being

more deeply weathered than the younger (e.g., Hawaii). During most of the year, moisture-bearing trade winds blow from the northeast; the volcanic domes orographically induce precipitation, and rainfall is thus appreciably higher on the windward sides, often exceeding 500 mm annually. Consequently, windward coasts tend to be more deeply dissected than those to the lee. The basic dichotomy between windward and leeward has also affected vegetation patterns (Ripperton and Hosaka 1942) and soil development (Cline et al. 1955), with major consequences—which we will shortly examine in detail—for indigenous agriculture.

Detailed Study Locations

Five valleys (Fig. 1) were selected as study locations, based on geographical variation and availability of archaeological data; an additional advantage is firsthand knowledge of all five locations. Table 1 presents certain basic environmental characteristics of these windward and leeward locations. All five valleys have similar geomorphological provinces (steep bounding cliffs, taluvial slopes, alluvial floodplain). The following are agriculturally significant variables: (1) rainfall, (2) hydrology, and (3) soils.

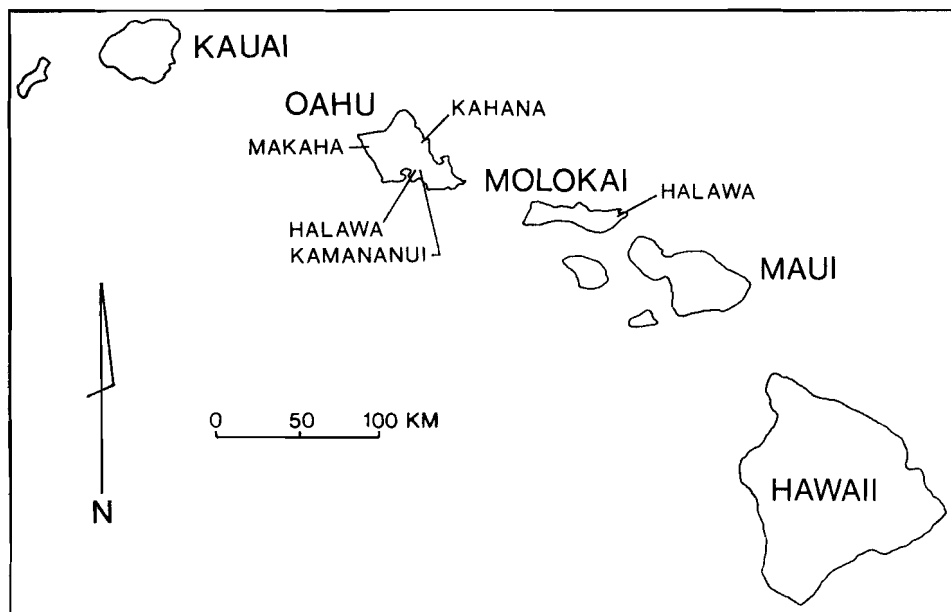


Fig. 1 The Hawaiian archipelago, showing locations of study areas discussed in the text.

Table 1 indicates rainfall parameters for the five study locations. In terms of adaptability to irrigated pondfield cultivation, hydrology (i.e., streamflow) is more significant than rainfall, although the latter is a major limiting factor for nonirrigated cultivation.

The capacity to develop irrigation systems is directly dependent upon constant and sufficient availability of water. Streamflow parameters for study locations are

TABLE 1. ENVIRONMENTAL CHARACTERISTICS OF STUDY LOCATIONS ON OAHU AND MOLOKAI ISLANDS

LOCATION	SIDE OF ISLAND	VALLEY LENGTH (KM)	SOIL FAMILIES*	ANNUAL PRECIPITATION† (MM)	STREAM FLOW PARAMETERS§			
					SIZE OF DRAIN-AGE BASIN**	AVERAGE DISCHARGE	MAXIMUM	MINIMUM
Makaha (Oahu)	leeward	7+	Kawaihapai Lualualei Molokai	500–2000	5.98	0.057	33.11	no flow
South Halawa (Oahu)	leeward	7.4	Kawaihapai Kalihi	1000–3500	22.74	0.311	104.99	no flow
Kamananui (Oahu)	leeward	8.1	Kawaihapai Kalihi	1000–3500	7.07	0.087	95.37	no flow
Kahana (Oahu)	windward	6.4	Kawaihapai Hanalei Kalihi Hauula Paddy	1500–6000	9.68	1.015	153.66	0.283
Halawa (Molokai)	windward	3.0†	Kawaihapai Hauula Paddy	375–2500	11.96	0.865	761.27	0.021

* Data from Cline et al. (1955).

† Figures indicate approximate range from coast to head of drainage basin.

‡ Valley length here is only to the waterfalls, and not to the head of the drainage basin, which is c. 8.

§ Data on streamflow derived from Wells (1961) and USGS (1971). All figures are cubic meters per second, which equals the rate of discharge representing a volume of water passing a given point in 1 second (1 cubic meter = 1000 liters).

** Size of drainage basin for which streamflow data were recorded, in square kilometers.

given in Table 1 (after Wells 1961; U.S. Geological Survey 1971; and Takasaki, Hirashima, and Lubke 1969). The high average basin discharges of windward valleys (Kahana and Halawa)—with over 0.8 cubic meters per second each—contrast with the leeward valleys. Even more significant is the factor of constant availability of water. Halawa and Kahana have perennial flow, while the leeward locations have no flow for several days at a time during parts of the year. One might expect to find such limiting factors expressed archaeologically, in differential degree of irrigation system development in windward and leeward valleys. Degree of flooding is also a factor important for agriculture. This was probably not significant in Kahana, where peak discharge equals only about 153 cubic meters per second (Takasaki et al. 1969, fig. 25), but in Halawa, where flood discharge can be as great as 761 cubic meters per second, flooding is a serious hazard to pondfield systems located along stream borders, and to irrigation ditch intake and diversion structures. The point should be stressed that where streamflow is highly erratic, as in Hawaii, consideration of discharge extremes is as important as the average discharge.

Streamflow additionally provided a source of pondfield soil and nutrients in its suspended-sediment load. Studies of sediment transport by Oahu streams indicate mean annual suspended-sediment yields of more than 650 tons per square mile (Jones, Nakahara, and Chinn 1971: table 5). Although such sediment would be carried in suspension during turbulent streamflow, much of this material was probably dropped in pondfields, where turbulence is minimal. Size distribution of suspended sediment is generally about 45 percent clay (< 0.004 mm), 40 percent silt (0.004 – 0.062 mm), and 15 percent sand (0.062 – 2.0 mm). Excavations in irrigation ditches in Halawa indicate also that sedimentation in the longer ditches may have required constant clearing.

Aside from hydrology, edaphic conditions are the most significant variable for cultivation. Table 2 presents soil distribution and composition data for the study locations, based on the islandwide soil survey by Cline et al. (1955). In distribution of soil types, Makaha is most divergent, while all other valleys share certain soil types. The majority of arable land area in Makaha comprises Dark Magnesium Clays and Low Humic Latosols.

In valleys other than Makaha, Alluvial Soils were of primary importance for agriculture. Those of the Kawaihapai Family are excellent for cultivation, being well supplied with bases, having a pH invariably greater than 6.0, and containing large amounts of calcium and potassium, as well as average amounts of nitrogen (Cline et al. 1955: 587). Hanalei Family soils have greater amounts of nitrogen and lower pH values, and are fairly fertile (1955: 603–605). Soils of the Kawaihapai and Hanalei Families formed the base for development of Hauula Paddy Soils in both Kahana and Halawa valleys. Gray Hydromorphic Soils of the Kalihi Family are common to South Halawa, Kamananui, and Kahana valleys on Oahu. These have a moderately acid (pH 5.0–6.0), sticky, plastic A_1 horizon, and highly mottled, blocky, plastic B horizon (1955: 559). Yields are less than with the Alluvial Soils and the Kalihi Soils are lacking in nitrogen, potassium, and phosphorus (1955: 559).

Most important for irrigated agriculture are the Hauula Paddy Soils. As they are specifically a manmade product, discussion of them is deferred until the archaeological stratigraphy of pondfields is considered in a later section.

TABLE 2. EDAPHIC CHARACTERISTICS OF STUDY LOCATIONS*

MAJOR SOIL CATEGORIES†	FAMILY	SERIES	PHYSICAL CHARACTERISTICS OF SOIL SERIES					MAKAHA	SOUTH HALAWA	KAMANANUI	KAHANA	HALAWA
			HORIZONS	DEPTH (cm)	COLOR	TEXTURE	PH					
Alluvial Soils	Kawaihapai	Kawaihapai	A ₁ C ₁ C ₂	76	brown to reddish brown	silt loam	6.0 7.0		+	+		+
		Mokuleia	A ₁ C ₁ C ₂ D	61	brown to red brown	silt loam	7.0 8.3					
		Pulehu	A ₁ C ₁ C ₂	76	brown to red brown	loam	6.5 7.5	+				
		Hanalei	Hanalei	127	brown to dark gray brown	silt loam	5.5 6.5					
Gray Hydromorphic	Kalihi	Kaena	A ₁ BC	76	dark brown	clay	5.0 6.0		+	+		
Dark Magnesium Clays	Lualualei	Lualualei	A ₁ B ₁ B ₂ C	167	very dark gray	clay	7.0 8.0	+				
Low Humic Latosols	Molokai	Ewa	A ₁ B ₁ B ₂ B ₃ C ₁	157	red to reddish brown	silty clay to clay	6.0 7.5	+				
Paddy Soils	Hauula			50	dark gray	mucky silt loam	5.5 7.0				+	+

* Data from detailed soil maps and soil descriptions, Cline et al. (1955).

† Comparable to Great Soil Groups.

The range of environmental conditions—climatic, hydrologic, and edaphic—characterizing the five study locations was sufficient to encompass the ecological templates of all major cultigens comprising the indigenous Hawaiian horticultural complex. At one extreme (Makaha) we might expect to find elaboration and modification of agronomic techniques stressing dryland cultivation of essentially xerophytic or tropophytic species, especially *Ipomoea batatas* and *Dioscorea alata*, while at the other (Kahana, Halawa) we might expect adaptation of hydrologic and edaphic regimes to the culture of hydrophytic *Colocasia esculenta*. The environmental range of this East Polynesian endpoint is, in short, a microcosm of the essential Oceanic contrast between wet and dry (cf. Barrau 1965).

AGRICULTURAL SYSTEMS

The following consideration of agricultural systems is based primarily on archaeological or other physical evidence of essentially environmental modification representative of prehistoric cultivation. Archaeological data are contained in the following sources: for Makaha, Yen et al. (1972), Morgenstein and Burnett (1972), Hommon (1969, 1970, 1972), and Rasor (1970); for Kamananui and South Halawa, Ayres (1970), Denison and Forman (1971), and Crozier (ms); for Kahana, Hommon and Barrera (1971); and for Halawa, Riley (1970, 1975), and Kirch (1970, 1971a, 1971b, 1972, 1975).

Irrigated Pondfield Components

We should first minimally define *irrigated pondfield system* as a set of artificially leveled planting surfaces designed to impound water, sharing a single water source, and forming a hydraulic unit for the purposes of irrigation. Using these criteria, archaeological remains of irrigated pondfield systems are found in all five study locations, with considerably greater emphasis in Kahana and Halawa valleys.

The term “pondfield” is used here in preference to “paddy,” as the latter has specific reference to rice. This distinction has not always been made; e.g., Cline et al. (1955) refer to Hauula Paddy Soils, which were developed under taro cultivation. Kyuma and Kawaguchi (1966: 119) have proposed that the term “Aquorizem” be used to signify paddy soils with their distinctive oxidation-reduction status. This term, signifying “paddy rice,” is an unfortunate choice, as it places emphasis on the crop (rice), rather than on the fundamental process of human-induced edaphic modification, the result of which is the same, despite the nature of the crop (rice or taro).

Pondfields

Essentially, pondfield construction is an agronomic modification of existing hydrologic and edaphic conditions where they are unfavorable to the growing of *Colocasia esculenta* (or rice elsewhere) by the creation of an artificial ecosystem (cf. Geertz 1963). The range of potential construction techniques is quite broad, as Spencer and Hale (1961) have demonstrated; those actually used in Hawaii, however, were more restricted. We may define pondfield types in Hawaiian valleys as a function of two minimal components:

- | | |
|---|--------------|
| a. wall or bund material, stone : nonstone | S:S |
| b. topographic placement, in streambed : not in bed | B: \bar{B} |

Of four logical combinations, only three are archaeologically known and they are sufficient to cover the reported range:

- | | |
|--|------------------|
| 1. stone-walled barrage pondfields | SB |
| 2. stone-faced slope or flat pondfield | S \bar{B} |
| 3. earth-faced slope or flat pondfield | $\bar{S}\bar{B}$ |

The first (SB) are what Spencer and Hale (1961:8) term "narrow channel barrage terraces." They were constructed by building a barrage of stones across a narrow stream channel (usually intermittent or with little flow) and allowing soil and rock to accumulate behind the stone facing, thus creating a level planting surface which spread and impounded the channel's waterflow. More common are stone-faced pondfields constructed either on taluvial slopes or alluvial terraces (S \bar{B}), but not directly in stream channels; this is the dominant pondfield type in the locations studied. Excavations in S \bar{B} pondfields in Makaha and Halawa reveal that the stone facing is generally a veneer of one-stone or two-stone thickness. Such facings apparently add stability to pondfields on steeper slopes; they may also be a means of removing unwanted loose stone from the soil media. These pondfields have been artificially filled, in contrast to the barrage fields which catch stream sediment. Earth bund pondfields ($\bar{S}\bar{B}$) have been noted on the floodplain at Halawa, where slope is minimal and loose stone not abundant; they probably also exist on the unsurveyed floodplain at Kahana.

Pondfield Soils

Excavations at Makaha and Halawa provide a corpus of stratigraphic profiles through pondfields, revealing the nature of fossil agricultural soils. The profiles exhibited are due to human action, and their development merits some discussion as they are distinct from naturally formed soil types. A clear example of a pondfield soil profile is seen in Trench 2 through an upper pondfield of Complex 1 in Halawa (Riley 1975), a portion of which is reproduced here as Figure 2. The profile is:

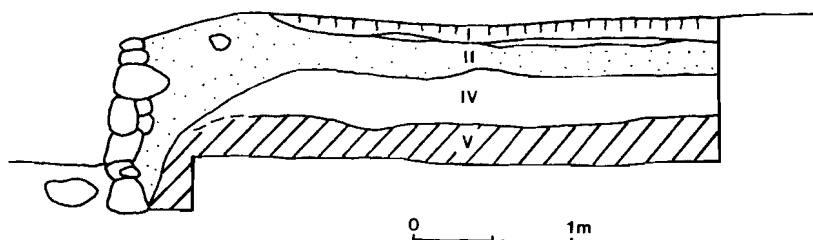


Fig. 2 Stratigraphic section of a trench through an archaeological pondfield at Kaio, Halawa Valley, Molokai (after Riley 1975).

Layer I	0-20 cm	Recent accumulation of humus and silt built up following cessation of pondfield cultivation
Layer II	20-25 cm	Soil A ₁ horizon of compact gray-brown clay-silt, somewhat plastic
Layer IV	25-30 cm	Soil B horizon of hard-packed gray clay with marked red ferruginous mottling due to oxidation; charcoal flecking
Layer V		Light brown alluvial Kawaihapai soil base (cf. Cline et al. 1955)

It has been pointed out by Cline et al. (1955: 121-123) and by Kyuma and Kawaguchi (1966; Kawaguchi and Kyuma 1969*a*, 1969*b*) that the waterlogging of pondfield soils under cultivation creates an eluviation, reduction state in the upper A horizon and an illuviation, oxidation state in the lower B horizon. This is due to the downward percolation of water, transporting exchangeable ferrous and manganous ions mobilized in the reductive A horizon to the B horizon, where oxidation causes ion precipitation and consequent mottling (Kyuma and Kawaguchi 1966: 118). Such chemical action has been widely reported for pondfield soils (either rice or taro) in Japan, Thailand, and Malaya (Kawaguchi and Kyuma 1969*a*, 1969*b*), although surprisingly van Breemen et al. (1970: 66) do not describe such profiles for the Ifugao rice pondfields. The contrast of this chemical regime to that prevailing in normal well-aerated soils is enormous, as demonstrated by analysis of ferrous-ferric and manganous-manganic systems in Hawaii on pondfield soils (data from Cline et al. 1955, table 35):

	pH	$K = \frac{Fe^{+++}}{Fe^{++}}$	$K = \frac{Mn^{+++}}{Mn^{++}}$
Hauula Paddy Soil	6.5	0.06	0.18
Normal well-drained soil	4.2	35.60	9590.00

Another physical feature of pondfield soils is the presence of limonite concretions. Morgenstein and Burnett (1972: 104) provide the basic analysis of these hydrated, iron-oxide tubes which apparently formed around *Colocasia* roots under aqueous conditions. While limonite tubes had not previously been reported, Sherman et al. (1949: 122) did note the similar occurrence of pyrolusite (MnO₂) concretions around sugarcane roots in Hawaiian soils. It is probable that the limonite concretions resulted from oxidation of the surrounding sediment by plant roots.

The chemical exchange systems described here have double significance for an archaeological consideration of pondfield cultivation: (1) they point up the essential agronomic *modification* of existing soil media for this kind of cropping, and (2) they provide the archaeologist with a tool for recognizing fossil pondfield soils in terms of the resultant profiles (eluvial A, illuvial B horizon, limonite tubes). These chemical distinctions, along with others such as textural difference, pH, or total organic content, may in the future find extensive use as criteria for the recognition of pondfield soils in archaeological contexts.

Another significant feature of fossil Hawaiian pondfield soils is the presence of charcoal flecking either in the lower B horizon, as in the profile described earlier, and at site OA-A7-45 in Kamananui Valley (Ayres 1970: 26, fig. 21), or in irrigation-deposited material as at Makaha (Yen et al. 1972: 91). Its presence is a good indicator of burning associated with either clearing or shifting cultivation, on the pondfield site itself—prior to terrace construction—or upstream from the site (in which case the charcoal is brought in as a part of the irrigation flow).

Irrigation Structures

Irrigation structures may be defined according to the following dyads:

a. water source	watercourse : nonwatercourse	$W:\bar{W}$
b. lining of ditch	stone : not stone	$S:\bar{S}$
c. pondfield water feed	multiple : not multiple	$M:\bar{M}$
d. function	irrigation : irrigation plus drainage	$\bar{D}:D$

The observed types of irrigation structures may thus be componentially defined:

1. artificial springs (cut in hillside)	$\bar{W}\bar{S}$
2. stream-diverting, stone-lined, directed feed ditch	$W\bar{S}\bar{M}$
3. stream-diverting, stone-lined, multiple feed ditch	$W\bar{S}M\bar{D}$
4. stream-diverting, stone-lined, irrigating and draining multiple feed ditch	$W\bar{S}M\bar{D}$

The use of artificial cutting of hillsides to tap the ground water table ($\bar{W}\bar{S}$) has been noted in Makaha Valley at Survey Area 17 (Yen et al. 1972: 80–82) and in Zone 101 (Hommon 1972: 53–55). Figure 3 shows a plan and diagrammatic cross-section of one of these features, excavated by Yen et al. (1972: 80–82, fig. 35; Morgenstein and Burnett 1972: 99–103, figs. 43, 44). A rectangular cut penetrates the slumped taluvium until the *in situ* altered saprolitic basement and water table are reached. Flow is directed from the cut downslope to the pondfields. This prehistoric adaptation may be a reaction to the erratic surface water resources of Makaha (cf. Table 1).

Common irrigation structures at all pondfield systems are stone-lined ditches, which diverted water from either a major or tributary stream and carried it to the system. Allocation of water into individual pondfields was through a single outlet at the uppermost pondfield ($W\bar{S}\bar{M}$), or, if the ditch ran along the periphery of the system, by outlets into individual pondfields ($W\bar{S}M\bar{D}$). The two large pondfield systems (Complexes 1 and 2) on the Halawa Valley floodplain (Fig. 4) were fed by ditches which not only supplied water for irrigation but also had an additional drainage function ($W\bar{S}M\bar{D}$).

The distinction between single and multiple pondfield water inlets from ditches ($M:\bar{M}$ earlier) is important in terms of crop scheduling. Multiple inlets allow certain pondfields to be dry while others are inundated, giving the system as a whole greater versatility. Early nineteenth-century records of land tenure for Halawa Valley (which are a continuation of the pre-contact usufruct rights) indicate that

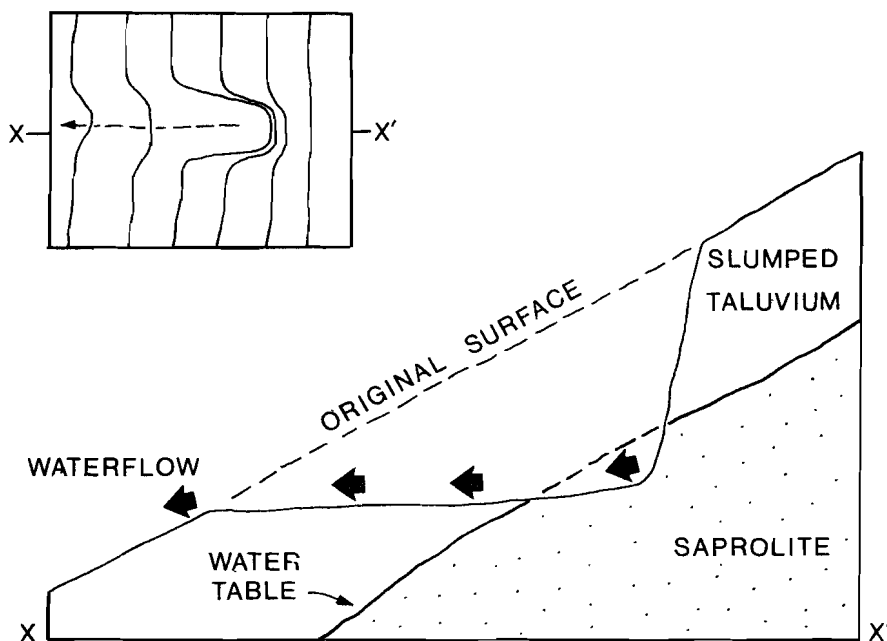


Fig. 3 Schematic plan and cross-section through an artificial cut in taluvial slope, designed to tap the water table, at Survey Area 17, Makaha Valley, Oahu.

corporate social groups, while sharing a single ditch, generally had separate pond-field intakes. Thus, pondfields in Halawa were usually owned in series running downslope from the water allocation point.

As with streamflow, it is necessary to consider ditch function not only in terms of average water allocation, but also in terms of controls for the protection of pond-field systems against erratically large volumes of water. Excavation at Survey Area 17 in Makaha (Yen et al. 1972) revealed prehistoric destruction of the upper series of pondfields by large quantities of erosional debris apparently deposited during flooding. Pondfield system 6 in Halawa (probably of early historic age) shows elaborate provisions for the prevention of large volumes of water entering the system during flooding of the main stream: (1) the ditch is curved, apparently to break the flow of water; (2) the uppermost terraces are protected on the upper side by a large, thick wall (c. 1.5 m high and 2.0 m thick) through which the ditch enters the uppermost field by means of a tunnel arrangement. At times of high water, the tunnel could be blocked and the flow diverted along the outer side of the heavy wall back into the main stream.

Irrigated Pondfield Systems

Having examined the constructional, edaphic, and hydrologic aspects of pondfields, we may integrate these and review the nature of several total *systems* as they are represented archaeologically. Some quantitative conception of scale is available in Table 3, providing data on ditches, pondfield statistics, total areas, and estimated water requirements for seven fossil systems and for a sample of 46 measured



Fig. 4 Generalized distribution of irrigated pondfields, irrigation ditches, and the limits of the zone of habitation (and shifting horticulture) in Halawa Valley, Molokai.

TABLE 3. STATISTICAL ANALYSIS OF IRRIGATED PONDFIELD SYSTEMS

LOCATION AND SITE NUMBER	TYPE	IRRIGATION DITCHES		PONDFIELD STATISTICS								ESTIMATED WATER REQUIREMENT (M ³ /SEC)	PERCENT AVERAGE STREAMFLOW REQUIRED	ESTIMATED CARRYING CAPACITY†
		N	LENGTH (M)	N	AREA			LENGTH (M)		WIDTH (M)				
					TOTAL (HA)	\bar{x} (M ²)	σ (M ²)	\bar{x}	σ	\bar{x}	σ			
Makaha Area 17	II	1		39+	>0.396	101.64	132.20	16.80	12.48	5.08	2.51	>0.0013	>2.28	>11
Makaha Zone 101	II			23	0.391	170.30	248.22	17.78	17.30	8.21	4.91	0.0013	2.28	11
Makaha sample*				46		159.00	191.95	17.41	13.64	8.17	3.79			
Kahana OA-F9-172	II?	1		9	0.079	88.00	57.55	11.61	5.75	8.92	2.19	0.0003	0.03	2
Kahana OA-F9-174	II?	1		11	0.068	62.63	35.78	13.27	8.41	4.90	0.97	0.0002	0.02	2
Kahana OA-F9-16	II	1	20	10	0.097	97.20	77.62	13.10	6.40	6.68	2.24	0.0003	0.03	3
Halawa Complex 3	III	1	470	37	1.002	270.97	237.05					0.0032	0.37	27
Halawa Complex 2	IV	2	1386 960	366	9.563	261.29	289.70					0.0310	3.58	258

* Combined sample of measured pondfields from the upper valley.

† Crude estimates of carrying capacity are based on the estimate by Massal and Barrau (1956) of irrigated taro yields of 12,000 lbs/acre, and on the assumption of a taro consumption rate of 2000 calories/person/day. This gives a figure of 0.037 hectares of irrigated taro necessary to support one person. Clearly, this estimate is intended for broad comparative purposes only.

pondfields in upper Makaha Valley. Estimated water requirements are based on Watson's (1970: 150) experimentally derived figure of $280 \text{ m}^3/\text{day/hectare}$ ($0.0032 \text{ m}^3/\text{sec}$) and have been computed as cubic meters per second so that comparison to actual available streamflow is possible (cf. Table 1).

While pondfields have been reported for South Halawa and Kamananui valleys on Oahu (Ayres 1970: 8–10, 39–40), no complete systems have been described. It is clear, however, that irrigated cultivation did not comprise a major component of the agricultural systems in these valleys. Probable causative factors include the total lack of flowing water in the streams at certain periods of the year, perhaps making it therefore more productive to intensify nonirrigated components, including possibly arboriculture.

The smallest and least elaborated pondfield systems are found in upper Kahana Valley (Hommon and Barrera 1971; see Table 3 in this paper). These systems are all fed from single irrigation ditches, either directly into the uppermost pondfields or with a peripheral ditch and individual pondfield intakes. The pondfields have stone facings and were constructed on low alluvial flats bordering Kahawainui Stream. Individual pondfields are small ($\bar{x} = 62\text{--}97 \text{ m}^2$) and required no more than 0.1 percent of the average daily discharge of Kahana Stream for system irrigation. None of these systems could probably have supported more than a single household unit, and such a unit would likely have been adequate for their maintenance.

Upper Makaha Valley contains a number of intermediate-sized systems, including Survey Area 17 and Zone 101 summarized here. The Survey Area 17 system has been extensively studied, both spatially and temporally (Yen et al. 1972; Morgenstein and Burnett 1972). Both systems were fundamentally fed by short ditches which emptied into the uppermost pondfields. They have, however, the added irrigation component of artificially dug springs to tap the water table, as discussed earlier (Fig. 3). Pondfield sizes are larger than those in Kahana, and greater total area required 3 percent or more of the Makaha Stream's average daily discharge for irrigation. The Zone 101 system could probably have supported about 10 persons; Survey Area 17, closer to 15–20.

The largest and most elaborate systems yet studied (Riley 1975) are in Halawa Valley, Molokai (Fig. 4). Complex 2, the largest in the valley, is situated on the north floodplain, and has two long stone-lined irrigation ditches. Average field size is about 260 m^2 ; with a total of 9.5 irrigated hectares, the system required 3.6 percent of the average daily discharge of Halawa Stream. Smaller pondfield systems (such as Complex 3) are located further inland on alluvial flats. While Complex 2 only required about $0.03 \text{ m}^3/\text{sec}$ of irrigation water, the combined total of pondfields in the valley required closer to $0.07 \text{ m}^3/\text{sec}$ or approximately one tenth of the average daily discharge. More important, however, is that at periods of minimal discharge ($0.021 \text{ m}^3/\text{sec}$) the water requirements of the combined systems greatly exceeded the available supply. In a valley where population is known to have been 500 or more persons (Riley 1975), this suggests that a social mechanism for water allocation may have been necessary. This was certainly true for the early historic period (Hutchins 1946; Nakuina 1893; Perry 1912; Wadsworth 1933; Watson 1970). Linguistic evidence on this point is also suggestive: the Hawaiian lexeme for 'water' is *wai*, and that for wealth, prosperity, ownership, or possession is *waiwai*; likewise,

the lexeme for 'law' is *kanawai*, literally, 'pertaining to water' (Handy and Handy 1972: 57-58).

Typology of Pondfield Systems

Table 4 (modified after Riley 1975) shows the presence or absence of a range of structural attributes of four types of pondfield systems, indicating the range of structural modification of environment and of system complexity and versatility implicit in these irrigated systems. An examination of these attributes suggests that only three dyads are necessary to achieve minimal and sufficient componential definitions of these types:

- a. water diverted : not diverted

b. direct feed : multiple feed

c. drainage plus irrigation : no drainage, irrigation only
- W:W̄

F:F̄

D:D̄

TABLE 4. ATTRIBUTES OF IRRIGATED PONDFIELD SYSTEM TYPES

ATTRIBUTES		TYPES			
		I	II	III	IV
Common attributes	level planting surface	x	x	x	x
	impounding of water	x	x	x	x
	creation of pondfield soil	x	x	x	x
Location	terraces in streambed	x			
	terraces on alluvial flat		x	x	x
	terraces on floodplain				x
Water	water diverted		x	x	x
Ditches	single ditch		x	x	
	two ditches				x
Ditch type	short termination ditch		x		
	peripheral ditch			x	
	irrigation/drainage ditch				x
Water allocation	one water allocation point		x		
	multiple water allocation points			x	x

Our four types, which appear to be adequate to cover the range of empirical data, are thus:

- I. Narrow channel barrage systems

II. Single ditch, direct feed systems

III. Peripheral ditch, multiple feed systems

IV. Multiple ditch, multiple feed, irrigation plus drainage
- W̄

WF

WFD

WFD̄

The layout of these types is shown schematically in Figure 5.

This classification points up the range of agronomic techniques used by prehistoric Hawaiians to create a microecosystem suitable for taro cultivation; the

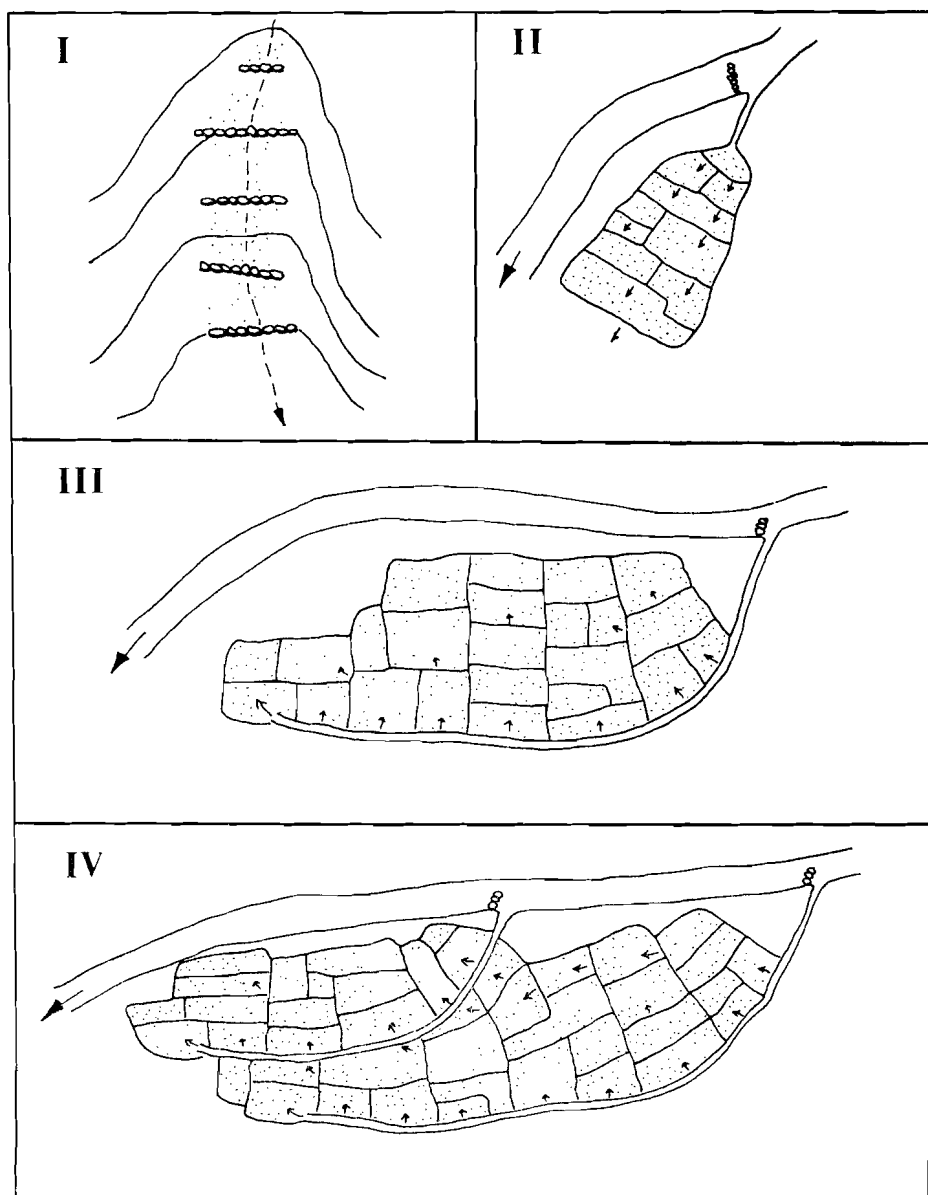


Fig. 5 Schematic representation of irrigated pondfield types. Planting surfaces are stippled; arrows indicate direction of waterflow. Not to the same scale.

environments modified include intermittent stream beds, alluvial flats, taluvial slopes, and alluvial floodplains. Structural aspects of the systems bespeak relative sophistication of hydrologic and edaphic management or alteration techniques.

Shifting Horticultural Components

As Barrau (1961) indicated, Polynesian agriculture in general encompasses systems of integral shifting cultivation (cf. Conklin 1957), in addition to intensive

pondfield cultivation. The essential contrast here is not only in relative permanence of subsystems but also in crop inventory, pondfield cultivation being monospecific, and dryland cultivation involving crop diversity (i.e., horticulture in the usual sense). (The characterization of pondfield cultivation here as monospecific is only in a relative sense, as it is true that the pondfield borders are often used for growing secondary crops such as *ti*, bananas, and sugarcane.) The more precise forms such dryland horticulture comprised in the Hawaiian environment, and to what degree they may have been articulated with intensive irrigated cultivation, are beginning to be shown by archaeological evidence.

One line of nonarchaeological evidence thus far little considered by prehistorians, which might indicate something of the range of the indigenous crop inventory in Hawaiian valleys, is the presence of cultigen survivals. (The term "cultigen survivals" is used here to denote cultivated clones which have survived in an area of past cultivation, despite the absence of any cultivation for the past few decades or centuries. All of these, as adventive species in the Hawaiian Islands, were first introduced into the area through cultivation.) Table 5 compiles data on the distribution of cultigen survivals in the five study areas and in Kipapa Gulch (Oahu), where the only relatively complete phytoecological study of a Hawaiian valley has been done (Hosaka 1937). The lists for Halawa and Kipapa are relatively complete, others less so. Unfortunately, quantitative data are entirely lacking, and should be obtained in future studies. It is known that in certain sections of Halawa Valley, breadfruit trees (*A. altilis*) are extremely plentiful, and may point to a possible earlier importance of arboriculture in that valley. Intensification of arboriculture as a subsistence strategy has been noted for other parts of Oceania; e.g., the Marquesas

TABLE 5. DISTRIBUTION OF CULTIGEN SURVIVALS IN STUDY LOCATIONS AND IN KIPAPA GULCH, OAHU

CULTIGEN SURVIVALS	KIPAPA	MAKAHA	SOUTH HALAWA	KAMANANUI	KAHANA	HALAWA
<i>Cocos nucifera</i> L.	x	x				
<i>Alocasia macrorrhiza</i> (L.) Schott	x				x	x
<i>Colocasia esculenta</i> (L.) Schott	x	x			x	x
<i>Cordyline fruticosa</i> (L.) A. Chevalier	x	x	x	x	x	x
<i>Dioscorea bulbifera</i> L.	x					x
<i>Dioscorea pentaphylla</i> L. cvr. PIIA St. John	x					
<i>Musa</i> spp.	x	x	x	x	x	x
<i>Piper methysticum</i> Forster	x					?
<i>Touchardia latifolia</i> Gaudichaud	x			x		
<i>Artocarpus altilis</i> (Park.) Fosb.	x				x	x
<i>Aleurites moluccana</i> Willd.	x	x	x	x	x	x
<i>Morinda citrifolia</i> L.	x					x
<i>Tacca leontopetaloides</i> (L.) Kuntze						x
<i>Hibiscus tiliaceus</i> L.	x	x		x	x	x
<i>Saccharum officinarum</i> L.						x

(Yen 1971; Handy 1923) and the Santa Cruz Islands (Yen 1974). The survival of domesticated species, in a semiferal state, also indicates the suitability of the natural climatic and edaphic conditions to their ecological templates.

Shifting Cultivation

Under normal, nonintensive conditions, we might not expect shifting cultivation to result in permanent or long-range structural modification of the environment which would permit archaeological reconstruction. However, if cultivation is intensified to the point where relatively permanent ecological damage is accrued—for example, in terms of erosion or grassland succession—it may be possible to find physical evidence representing such activity. This apparently was so in Halawa and Makaha valleys, where in both cases a present-day transitional flora indicates extensive disruption of endemic floral associations in the past. Present-day dominants in Makaha are the introduced *Schinus terebinthifolius* Raddi., *Eugenia javanica* Lam., and *Leucena glauca* (L.) Benth., while the latter is also dominant in Halawa. Both locations, however, exhibit remnants of an earlier association of endemic *Acacia koa* Gray and *Eugenia sandwicensis* Gray, with *Osteomeles sandwicensis* (Sm.) Lindl. and *Dodonea eriocarpa* Smith also in Makaha. Hosaka (1937: 203) notes that *A. koa* and *E. sandwicensis* are both major components of middle- to higher-altitude native Hawaiian forests.

This floral evidence for a putative prehistoric disruption of endemic phytoecology is further substantiated by stratigraphic, datable material in both valleys. In Makaha, this is provided by the presence of erosional debris, containing charcoal (to be expected from swidden activity), which inundated and sealed in the lower layer of pondfield cultivation at Survey Area 17 (Yen et al. 1972: 90–94, fig. 41); this event may be approximately dated to 1550 A.D. (1972, Table 4). In Halawa, stratified alluvial outwash and slumped taluvium at the base of a southern slope subvalley suggested previous slope instability. The earlier erosional deposits contained thousands of endemic subfossil terrestrial gastropods (Kirch 1972; 1975) of 13 species in five families (Endodontidae, Achatinellidae, Amastridae, Succineidae, Helicinidae). None of these snails, which are highly specialized to endemic flora, are to be found in the area today. Hence a different, endemic flora must have covered the slopes previously. In addition, the erosional deposits contained abundant charcoal, to be expected if the destruction of the original forest and consequent slope instability and erosion are to be attributed to the effects of shifting cultivation. Finally, radiocarbon dating of this charcoal (Gak-2744) clearly placed the time of burning well within the span of human occupation of the valley (750 ± 90 B.P.). In sum, in Makaha and Halawa both, there is ample evidence of major disturbance of endemic floral associations, indicated by a present-day transitional flora, by slope instability, and by erosional deposits containing both charcoal and endemic land snails, which can only be attributed to the action of shifting cultivation involving burning.

Shifting Cultivation with Structural Modification

While the kind of shifting cultivation evidenced by the data just described resulted in environmental degradation, it did not involve any *intentional* structural

modification of the existing hydrologic or edaphic conditions. Large areas in all five study locations, however, contain archaeological remains precisely indicating purposeful modification. We might hypothesize that such landscape alteration reflects some degree of *intensification* of shifting cultivation, with agronomic attempts at transformation of local microecology to favor the growing requirements of certain cultigens, and with probable reduction in fallow length.

An example of structural modification for horticulture can be seen in the Kapana area of Halawa Valley (Fig. 6). This slope of stony Kawaihapai Family Soil (Cline et al. 1955) is bisected by Makaeleele Stream, a tributary of the main Halawa Stream. Both streams provided water for two systems of irrigated pondfields in Kapana, to the west of Makaeleele. Most of the artificially prepared planting surfaces (stippled areas) east of Makaeleele are not true pondfields, but rather only partially leveled terraces bordered by low (c. 50 cm high) stone facings. These crude terraces were built across shallow intermittent gullies on the taluvial slope, and are in some ways analogous to the Type I pondfield systems defined earlier. In terms of horticultural function, these terraces probably served (1) to retard erosion of garden areas, (2) to retain water in the planting surfaces, (3) to provide a moderately level planting surface, (4) to clear the soil of larger stones, and (5) as plot or manageable unit borders. Even today, with the area completely covered in secondary growth, these terraces support semiferal *Dioscorea bulbifera*, *Cordyline fruticosa*, and *Morinda citrifolia* in some abundance. The low ridges between terraced gullies are covered with numerous breadfruit trees, suggesting an arboricultural element. Habitation and ritual sites are distributed throughout this horticultural zone, along with free-standing stone walls and pens. Several of these sites have been excavated (Hendren 1975), date to a period from about 1400 to 1800 A.D., and possibly indicate shifting residence. Thus, at Kapana a pattern of intensive pondfield cultivation and shifting horticulture with structural modification, combined with elements of arboriculture, is evidenced. Articulated with this settlement pattern (i.e., ecologically oriented behavior; cf. Chang 1967) is a community pattern of secular and ritual sites representing the social aspects of this total economic system. Kapana provides a virtually typic situation of windward or wet valley agricultural systems.

Kamananui and South Halawa valleys on Oahu present a contrast in the paucity of structural modification attributable to horticulture. Although terraces similar to those described earlier exist, as do stone mounds, they are not common (Ayres 1970: 8-13, 39-42). This absence cannot be explained as due to sparse prehistoric occupation in these valleys, as residence and ritual sites are plentiful and excavations reveal a time depth for occupation extending back at least to 1450 A.D. (Ayres 1970; Denison and Forman 1971; Crozier ms). We have already noted the excavation of charcoal in a terrace by Ayres, suggestive of shifting cultivation with burning. It thus seems reasonable to suppose that the nonirrigated component of agriculture in these valleys, which was clearly dominant, was composed largely of shifting cultivation with an unknown element of arboriculture. A thorough, quantitative phytogeographic study might provide better criteria with which to judge this hypothesis.

At the other environmental extreme, represented here by lower Makaha Valley, we find a totally different type of structural modification, again attributable to dryland cropping. Archaeological Zone 1 in lower Makaha is one of the most intensively studied groups of sites in the archipelago, with detailed maps of Sub-

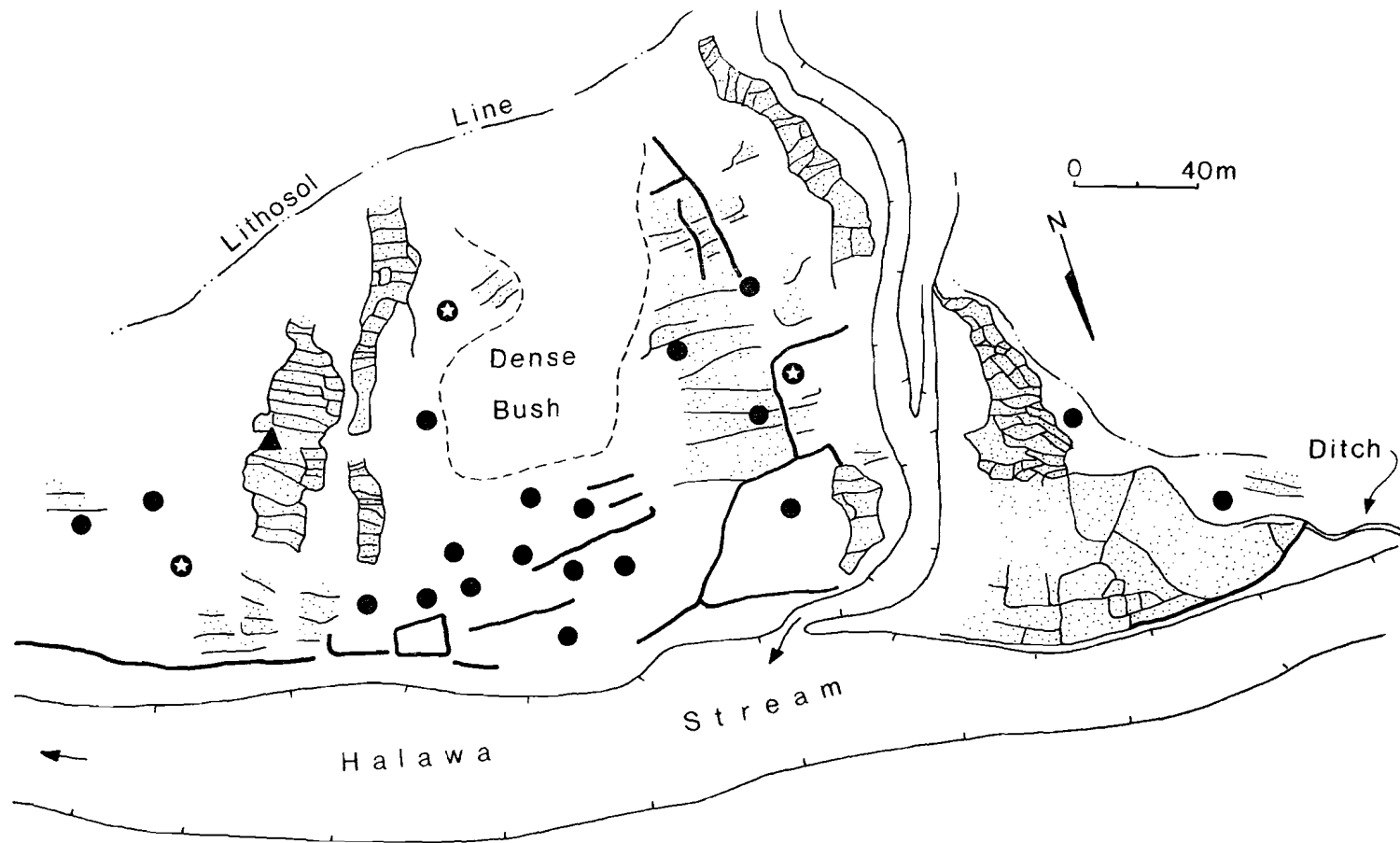


Fig. 6 Generalized map of archaeological features in Kapana, Halawa Valley, Molokai. Planting surfaces are stippled; heavy lines indicate free-standing walls; solid dots indicate habitation sites; starred dots indicate ceremonial sites (probably men's houses). A portion of the area could not be mapped due to extremely dense bush.

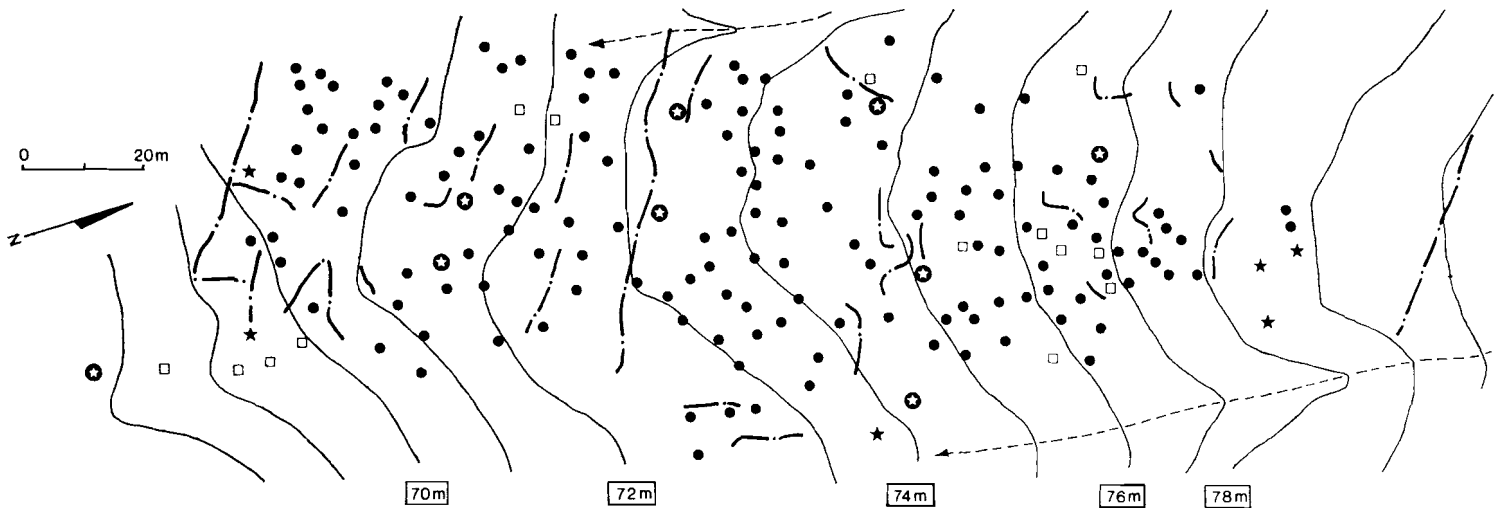


Fig. 7 Diagrammatic map of Subzone 1A at Makaha Valley, Oahu (modified after Hommon 1969). Contours (1-meter interval) slope from north to south. Dashed lines indicate intermittent streamflow. Archaeological features are: dashed-and-dotted lines = low stone "field borders"; dots = stone mounds; squares = clearings; starred dots = habitation sites; and stars = enclosures.

zones 1A and 1C provided by Hommon (1969, 1970), and results of excavations by various investigators (Takayama and Green, 1970; Rasor 1970; Takayama 1969). Radiocarbon dating of associated habitations indicates a time range of 1100 A.D. to contact (Green 1970). Hommon's map of Subzone 1A has been redrawn here (Fig. 7) in more schematic form, indicating the distribution of structural features over the landscape (total area = 14,000 m²), including (1) 145 mounds, (2) 14 clearings, (3) six enclosures, (4) nine habitation sites, and (5) low stone "field borders." Excavation of a clearing by Rasor (1970) revealed that this was another type of residence site, perhaps temporary, defined minimally by the presence of a hearth. It was hypothesized that the large number of mounds essentially represented manipulation of edaphic conditions by removal of stones from the planting areas, and that if so, these mounds should exhibit a random distribution over the ridge area; in contrast, the habitation features might be expected to be nonrandom. To test this hypothesis, a nearest-neighbor analysis (Clark and Evans 1954) was performed, with the results, as presented in Table 6, tending to confirm our expectations. The structural features evidenced in lower Makaha thus suggest that here agronomic modification was directed largely to the edaphic media, and included (1) stone removal, (2) providing of low enclosures for some plants (cf. Barrau 1961, fig. 19a), and (3) possible erosion control with cross-slope field borders.

TABLE 6. NEAREST NEIGHBOR ANALYSIS OF RANDOM DISTRIBUTION OF STRUCTURAL MODIFICATION IN SUBZONE 1A, MAKAHA VALLEY

STATISTIC	MOUNDS	ENCLOSURES	CLEARINGS	HABITATIONS
Number of sites	145	6	14	9
Density (ρ)	0.01	0.0006	0.001	0.0004
Mean distance (\bar{x})	4.98	24.00	10.57	24.55
\bar{x} in infinitely large random distribution of density ρ	4.91	24.15	15.81	19.72
R*	1.01	0.99	0.66	1.24
	random	random	nonrandom	nonrandom

* Measure of deviation of actual mean distance from the mean distance of an infinitely large random distribution of density ρ : 1.00 is random, 0.00 is maximum aggregation, 2.1491 is maximum spacing.

In addition to the extensive use of mounds, the Zone 1 archaeological remains include apparent attempts at control of intermittent water flow, or what Hommon has termed "dry-land irrigation" (1970: 32); this is particularly evident in Subzone 1C (1970, fig. 4). Particular structural modifications include cross-gully "dam-terraces," diversion and retaining walls, and putative crop plots defined by cleared areas. Hommon concludes that these largely informal structural modifications were built to "... take advantage of the heavy but unpredictable and infrequent flows of water in the talus wastes" (1970: 33).

Despite the extent of edaphic modification in lower Makaha, we should not conclude that occupation and horticultural utilization of the region was on a permanent basis. On the contrary, the evidence from excavation and dating of nine

associated dwellings of field shelters (primarily C- and L-shaped stone-walled sites), strongly points to a pattern of short-term, shifting residence (Takayama and Green 1970: 54; Green 1970: 102-104). Thus, we still are within the range of a modified, perhaps intensified, but nonetheless shifting form of horticulture.

Looking now at the range of modification documented in relation to salient environmental parameters, a probable pattern emerges (Table 7). In Halawa, the dominant terracing is an agronomic adaptation to wet conditions, where intermittent water flow in gullies is common, whereas at the opposite extreme in Makaha, stone mounding is an adaptation to relatively arid conditions. In terms of probable crop composition, we would expect hydrophytic species to have dominated in Halawa, whereas relatively xerophytic (or at least more adaptable) *Ipomoea batatas* and tropophytic *Dioscorea alata* were probably dominant in Makaha. Kamananui and South Halawa valleys on Oahu seem to occupy an intermediate position on this sliding environmental scale, where conditions were not wet enough to warrant extensive use of terracing, nor arid enough to require extensive stone removal. In all cases, the data indicate that horticulture practiced in valley environments, whether or not it involved intentional ecological modification, was shifting (albeit with probable variable fallow length).

TABLE 7. CONTRAST BETWEEN WINDWARD AND LEEWARD VALLEYS IN RELATION TO STRUCTURAL MODIFICATION FOR SHIFTING HORTICULTURE

CHARACTERISTICS	HALAWA	KAMANANUI	MAKAHA
Hydrology	WET ←————→ DRY		
Soil	alluvial	alluvial	Dark Magnesium Clays and Low Humic Latosols
Agronomic modification	terracing	swidden with minimal structural modification	mounding, clearing
Probable crop emphasis	Hydrophytic and arborescent (<i>Colocasia</i> , <i>Artocarpus</i>)	intermediate (all species)	xerophytic and tropophytic (<i>Ipomoea</i> , <i>Dioscorea</i>)

Arboriculture

The significance of arboriculture in the indigenous Hawaiian systems as yet another possible modification of shifting horticulture is still unclear. Evidence of other Oceanic systems is suggestive, including the continued use of tree crops (such as coconuts and bananas) in secondary growth among the Hanunoo integral shifting cultivators (Conklin 1957), intensification of arboriculture through selection in the Santa Cruz and Reef Islands (Yen 1974), or the former dominance of breadfruit in the Marquesan agricultural systems (Handy 1923) and those of the Society Islands (Handy 1930). In the latter areas, as well as in parts of Western Polynesia and

Micronesia, anaerobic fermentation and preservation of breadfruit paste is associated with the cultivation of *A. altilis*. In Hawaii, cultivated arborescent species included *A. altilis*, *Cocos nucifera*, *Musa* spp., as well as the economically useful although largely inedible *Pandanus odoratissimus*, *Touchardia latifolia*, *Aleurites moluccana*, *Cordia subcordata*, *Hibiscus tiliaceus*, and *Morinda citrifolia*. Intensive cultivation of tree crops was noted during early historic times by, among others, Portlock (1789: 74) and Arago (1823: 119–120), the latter of whom referred to “. . . double rows of banana, bread-fruit, cocoa-nut . . .” at Lahaina, Maui Island.

We have already noted the presence of relatively large numbers of semiferall breadfruit trees in portions of Halawa Valley. Quantitative distribution studies of cultigen survivals may be useful in further assessing the extent of arboriculture in indigenous Hawaiian agriculture.

The apparent absence of anaerobic pit fermentation and preservation of breadfruit paste (Yen 1971) in Hawaii, as indicated ethnohistorically, is somewhat surprising, given the importance of this technique elsewhere in Polynesia, including the Marquesas. Recent excavations in prehistoric residential sites in Halawa and South Halawa valleys have, however, revealed the existence of large stone-lined pits (c. 1 m deep) which may conceivably have been used for this purpose (Hendren 1975; Crozier ms). Verification of this hypothesis must await further excavation.

Animal Husbandry

In considering total agricultural systems as formed of a series of reticulate subsystems, the integration of animal husbandry, especially of pig raising, with tropical Pacific agriculture (Yen 1968: 407; 1971: 11; Brookfield 1968: 426; Brookfield with Hart 1971: 16–17, 86–87) must be taken into consideration. Lewthwaite (1964: 16–17) noted the inclusion of animal husbandry with early Tahitian agriculture. Large numbers of hogs were obtained by Cook (King 1778) at Kealakekua, indicating the capacity of native cultivation to support such a population. Ellis (1825) observed in 1823 that dogs were raised, *primarily on vegetables*, as an article of food, and Hartwig (1868: 32) indicated that dogs were fed primarily on taro.

Archaeological evidence for extensive animal husbandry is considerable, including structural evidence such as pens (Yen et al. 1972: 62) or walls designed to keep animals out of garden areas, and actual faunal remains. The most completely studied faunal assemblage excavated to date, from the A1-3 site in Halawa (Kirch 1971a, 1975), includes both dog and pig bone, apparently representing managed populations (indicated by young age of total population, based on unfused epiphyses, tooth eruption, and other indicators). These populations increased steadily from initial occupation of the valley in c. 650 A.D. until site abandonment after 1300 A.D., putatively in tandem with the development of the valley's agricultural capacity.

This integration of managed populations of domestic animals with cultivation in a total agricultural system has important ramifications in terms of calculation of total carrying capacity of the systems, or of intensification.

Valley Agricultural Systems: A Synopsis

A range of agronomic techniques from those involving maximal alteration and utilization of the environment (pondfields) to those involving little more than floral

alteration (arboriculture), and spanning an equal diversity of valley environments from high rainfall with alluvial soils to arid with rocky soils, has been documented. The indigenous agricultural systems which once occupied these five study locations invariably included both irrigated pondfield and horticultural subsystems. Thus, at the grossest level we may characterize Hawaiian valley agriculture as having been composed of *mixed* systems of both permanent and shifting cultivation (cf. Yen et al. 1972).

We have referred to an agricultural system as composed of several reticulate subsystems—the foregoing analyses now permit a categorization of the range of subsystems involved. Leaving aside the animal husbandry subsystem, and dealing only with cultivation, we may provide minimal, distinctive componential definitions for four subsystem categories, based on these agronomic features:

S:̄S Shifting : nonshifting

A:̄A Aqueous planting environment : nonaqueous planting environment

P:̄P Permanent modification : nonpermanent modification

T:̄T Tree-crop emphasis : nontree-crop emphasis

The categories and componential definitions are (boldface letters are mnemonic devices for the categories):

P	Irrigated Pondfields	S̄AP
SM	Shifting Cultivation with Permanent Modification	S̄AP̄T
S	Shifting Cultivation (no permanent modification)	S̄AP̄T̄
A	Shifting Cultivation with Arborescent Emphasis	S̄AP̄T̄

Conklin (1967: 108–111) has shown that finite directed graphs are useful for expressing temporal, sequential links between spatial forms, and has used such a graph to represent relationships between eight Ifugao land form types. Borrowing this method from Conklin, and altering certain symbols, the *potential* sequential links between our four subsystem categories defined here may be diagrammed (Fig. 8). We need to add three subsystems: (1) climax forest, indicated by **F**; (2) secondary growth, **Se**; (3) grassland climax, **G**. These nonagricultural subsystems are shown by triangles, whereas the agricultural categories are squared. Directed lines indicate the possible changes, and recursive loops represent continuous cyclic progression. Symbols within the loops refer to minimized versus maximized cycles.

Whereas Conklin's directed graph for Ifugao is based on "ethnographically attested" sequences, Figure 8 represents only an hypothesized series of links, based on archaeological or other empirical evidence. Using this graph as a model, however, it may be possible to test the proposed linkages. For example, extensive evidence of burning and/or local erosion stratigraphically evidenced beneath pondfield soil profiles (as at Halawa, cf. Riley 1975) is indicative of a sequence from **F** → **S** → **P**. The present transitional state of the ridge and plateau flora in upper Makaha Valley, with indigenous grass species dominant (Yen et al. 1972: 65, fig. 25), suggests **F** → **S** → **Se** → **G**. Certain inland locations in Halawa may have had a sequence of **F** → **S** → **SM** → **Se** → **F**. These examples merely indicate that

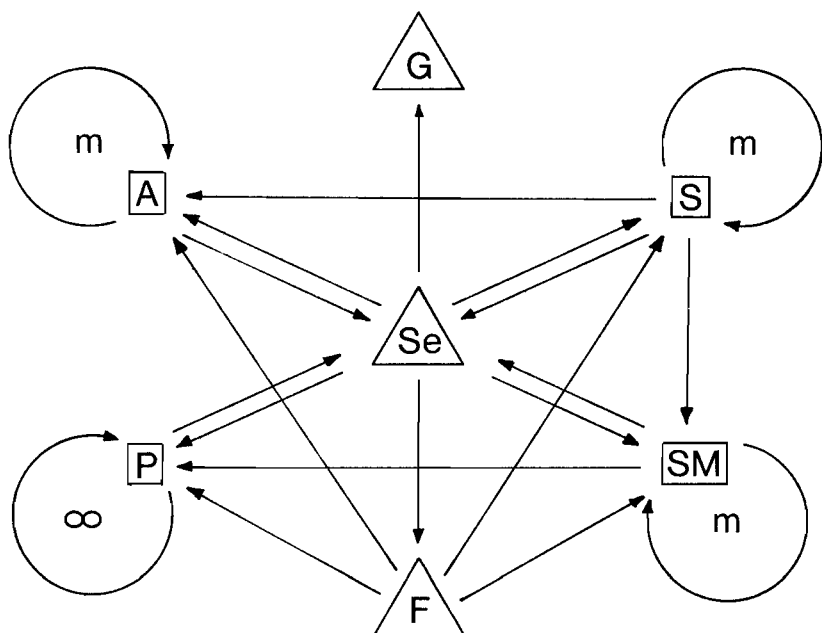


Fig. 8 Directed finite graph of hypothesized sequential links between agricultural subsystems (in squares) and noncultivated floral associations (in triangles).

this model may be of future heuristic value in looking at agricultural *development* or *change*. That such change took place is abundantly indicated in the archaeological data thus far accumulated. Hence we are also faced with the problem not only of synchronic system characterization, but also of determining longer diachronic trends or trajectories of agricultural change.

THE PROBLEM OF INTENSIFICATION

This question of time includes the problem of intensification of agricultural systems (cf. Boserup 1965; Brookfield 1972; Waddell 1972; Yen 1973). Some discussion of the Hawaiian data in terms of intensification may be valuable. We must first enquire, what is the definition of intensification and how are we to recognize the process, archaeologically or otherwise? Boserup (1965: 43) used criteria of technological advancement allowing increased cropping of a unit of land; this, however, does not appear to be entirely satisfactory. We might instead consider intensification, as Rosendahl (1972: 536) has done, as "... any changes which tended to increase the level of total agricultural productivity." This is an improvement over Boserup in that not only crop scheduling but other kinds of agronomic adaptations are considered. Probably the best attempt to date at disentangling the concept of intensification has been Brookfield's (1972), whose ideas to some extent parallel those of Yen's most recent formulation (1973; personal communication, January 1973). Brookfield (1972: 46) stresses that (1) the ecological study of agronomic adaptations must take cognizance of the wider context of human be-

havior, that is, in terms of "... an understanding of human needs and motivations," and (2) we need to revise our theory of production so that it takes into account the *general pressure of needs* rather than being restricted to a population-based, calorific-obsessed theory. Clearly, the relation of production to the needs of entire social systems (including items such as prestation and ritual, and not merely subsistence) is significant in regard to this second point.

This suggests that we might profitably examine intensification of indigenous Hawaiian agricultural systems as development of agronomic adaptations in response to the pressures of both environment and societal needs, including, but not restricted to, subsistence needs. In this essay, we have projected backward from the ethnohistoric endpoint into the prehistoric period, using archaeological data to define valley cultivation systems. Considering agricultural development in Hawaiian valleys as a developmental process, we must now reverse the sequence and attempt to define the cultural set of agronomic techniques and the adventive crop plant inventory comprising the agricultural systems of initial colonizers in the archipelago. The earliest sites yet excavated, at Waimanalo (Oahu) and Halawa and dating to approximately the seventh century A.D. (Pearson, Kirch, and Pietrusewsky 1971; Kirch 1971a, 1975), are both situated in windward areas, focal to a wide range of microenvironments, including open sea, littoral, freshwater streams, floodplains with alluvial soils, and higher taluvial slopes. Artifactual and faunal analyses indicate that the economic systems of these early settlers were correspondingly wide-ranging, and that they exploited a broad ecological spectrum. Both sites contain dog and pig bone, suggesting the concurrent existence of a more inclusive horticultural complex. We may reasonably expect that the inventory of cultivated species was essentially that present at the time of European contact (or possibly broader, if anything), although the dominant status of certain cultigens may have been different. Likewise, considering the virtual pan-Polynesian distribution of agronomic techniques including both shifting (slash-and-burn) cultivation and some form of hydrologic and edaphic modification for irrigation of *Colocasia*, we may expect both of these techniques, in their generalized forms, to have been part of the cultural equipment of the early settlers. With regard to such transfer of *agricultural concepts*, Yen has written:

Subsistence systems may be seldom transported *in toto*, and cultural methods may or may not be transferable without immediate modification; however, the *concepts* that underlie *method* are a part of the cultural armoury transferred. Such basic ideas as that taro requires a wet edaphic medium and yam requires a dry are as permanent as the species occupying roles in subsistence plant patterns. They remain a part of what has been variously described as the underlying lore or the ethnoscientific basis of so-called primitive agricultures. (Yen 1973: 70)

Given these premises, partially supported by archaeological data, of the simultaneous introduction into the archipelago of (1) the basic cultigen inventory, (2) the idea of shifting cultivation, and (3) the idea of hydrological and edaphic modification for *Colocasia* culture, we might posit a sequence of agricultural development reflecting a change in dominance (quantitative) rather than a qualitative change (Yen 1971; Kirch 1971b). We would expect, then, the modification and elaboration of this initial base in response to ecological and societal pressures.

Excavations in Halawa Valley, Molokai (Kirch 1970, 1971*a*, 1971*b*, 1972, 1975; Riley 1970, 1975; Hendren 1975) have provided the longest continuously documented sequence in the archipelago, and while we need not summarize the results here, suffice it to say that the succession of forms of agricultural activity represented in the data follows essentially the pattern just predicted. It seems also that the particular forms of agricultural development in the valley were a response to a complex interaction of both social and ecological factors, including (1) limiting factors in the environment, (2) tripping of the delicate endemic floral balance on the valley slopes, (3) population growth, and (4) the demands of an ever-increasing stratified society for ritual expenditures. All these factors must have played a part in determining the final form of the valley's indigenous agricultural system at its contact period endpoint, which was characterized by massive Type IV irrigated pondfield systems. The social needs as a causative factor in this kind of intensification (or involution, given the general plasticity of pondfield cultivation over shifting cultivation; cf. Geertz 1963), are suggested not only in terms of a population density of 300 persons per square kilometer (caloric needs) but also by the remains of several major ceremonial sites bespeaking a large, and probably demanding, social and ritual order.

In sum, intensification of prehistoric agricultural systems in Hawaii must be viewed as the interaction of an initial set of cultigens and agronomic technology (or concepts) with both the limiting factors posed by local environment and general social needs. Thus, we expect a gradual, quantitative change. The adequacy of this model will be tested only through further fieldwork.

CONCLUDING DISCUSSION

With the aid of archaeological and other empirical data, it is possible to characterize indigenous Hawaiian systems of valley agriculture—now represented as prehistoric remains—as having comprised dual, reticulate subsystems of irrigated pondfield cultivation and shifting horticulture. The horticultural subsystem itself exhibited a range of agronomic adaptation extending from essential slash-and-burn cultivation to fairly extensive modification of edaphic and hydrologic conditions. Categorization of agriculture into four subsystems allows predictive sequences of change from one form to another, in a fashion amenable to empirical testing. It has also been suggested that a meaningful consideration of intensification must take into account the putative agronomic concepts and cultigen inventory of initial colonizers, the limiting factors of local ecology, and the general pressure of social needs.

Indigenous Hawaiian systems are an eastern endpoint of a process of insular transfer of systems based on the vegetative reproduction of a set of Asiatic species, with probable elaboration and inclusion of new species and cultivation practices in the New Guinea-Melanesian area. Ultimate origins of this broad agricultural type, dominated by the taro-yam complex, doubtless lie somewhere in East and Southeast Asia. Of what general relevance, then, is a consideration of its eastern and temporally latest fringe? To the Polynesian specialist, the significance lies in the elucidation, spatially and temporally, of the character and development of a kind of agriculture widely distributed in the triangle subtended by Hawaii, Easter Island, and New

Zealand. The distribution of dual systems of cultivation, with both irrigated and shifting components, is extensive to this area, including the Marquesas, Societies, Rapa, Tubuai, Cooks, Futuna, and Uvea (Handy 1923, 1930; Aitken 1930; Allen 1971; Burrows 1936, 1937). Furthermore, there are unknown relationships with similar dual systems in Melanesia, including Fiji, New Caledonia, the western Solomons, and the New Hebrides (Sahlins 1962; Barrau 1958; Glaumont 1897; Chikamori 1967; Bonnemaïson 1974). In broader terms, a consideration of Polynesian agriculture may further provide suggestions for the possible form of the postulated earlier taro-yam agricultural complex of Southeast Asia (Sauer 1952; Solheim 1969), now largely supplanted by systems based on rice.

Perhaps the major significance of the recent prehistorical studies of Hawaiian agriculture is in the elaboration of a research design with extremely broad potential throughout the Malayo-Oceanic region. In the humid tropics, agricultural prehistory based on methods advanced in arid regions, that is, on the recovery of direct macrofossil evidence of domestication and cultivation, is likely to be foiled due to both a lack of good preservation and the tuberous, cormogenous, or fruity nature of the cultigens themselves. Rather, we might expect that an elaboration of the basic approach outlined in this essay, of the examination of permanent structural modifications wrought in the environment as a result of native agronomy, is likely to be the most rewarding. We may hope that further variations on the theme outlined here will eventually result in a more thorough knowledge of the development of agriculture in the Malayo-Oceanic region.*

* The viewpoints expressed in this paper owe much to the influence of Douglas Yen and to discussions with my archaeologist colleagues Thomas Riley and Paul Rosendahl. An earlier draft of this paper was read by K. C. Chang, H. C. Conklin, L. Pospisil, T. Riley, and D. E. Yen; their constructive comments are appreciated. None of them is to be burdened with the responsibility of statements made in this paper.

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